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Will the New Economy Emerge as Information Technology Pays Off?

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Abstract

During the past 30 years, the U.S. economy, along with the economies of other industrialized countries, has experienced several noticeable trends: an economic slowdown, a tremendous increase in the amount of information technology investment, and a increasing flow of workers from production to information sectors. With slow economic growth and fast IT capital accumulation, the so-called "information technology productivity paradox" has become a prevailing concept in the literature. Many researchers have attempted to solve the paradox by firm-level analysis. Indeed, a macroeconomic analysis, using a nation as an analysis unit, is not common in MIS research. By considering the complex triangular relationships of the above economic trends, this paper applies econometric models and macroeconomic theories to try to solve the IT productivity paradox. Emphasis is placed on the impact of information technology impact on the flow of workers from the production to the information sector and on the effect of

such a flow on productivity. The paper demonstrates that the flow could unravel the IT productivity paradox and provide a prediction of future economic growth.

Keywords: Employment, information technology productivity paradox, investment, economic growth.

I. INTRODUCTION

The purpose of this paper is to explain the information technology (IT) productivity paradox at a macroeconomic level. The goal is not to show how much productivity gain will be generated if one dollar of IT investment is made; rather, it is to explain why, in the past 40 years, a labor productivity slowdown came despite huge IT investments. Therefore, the focus will be on labor productivity: the ratio of output value to the number of workers. This negative correlation between labor productivity growth and IT investment may be a consequence of a dynamic change in an economy. The conjecture is that the change in labor force composition may be the cause, and that once this factor is isolated or discontinued, we can more clearly see the IT contribution to labor productivity. Such macroeconomic dynamics can only be investigated with a macroeconomic analysis.

The second reason for being interested in macroeconomic analysis is to resolve the discrepancy between recent firm-level analyses and the negative relationship between IT and labor productivity at a macroeconomic level. Some recent firm-level analyses (Brynjolfsson and Hitt 1995, 1996; 1996; Dewan and Min 1997; Hitt and Brynjolfsson 1996; Lichtenberg 1995) found very positive IT productivity using similar data sets. However, during the same time period spanned by the data in those studies, IT investment was negatively correlated with labor productivity growth. This “economic slowdown,” with its huge increase in IT investment, conflicts with those firm-level discoveries. Such a discrepancy needs to be resolved. We would like to understand why firm-level evidence of IT productivity was not apparent at the macroeconomic level. Again, we want to see if IT can reveal its contribution to productivity once the relevant factor is identified.

The paper is organized as follows. First, a literature review is provided to explain why macroeconomic research such as this is important and how this approach can compensate for the limitations of previous research. In section III, evidence is provided for the economic slowdown identified in section II. We note that the slowdown is not unique to the U.S., but is also an international phenomenon, by providing some explanations for the slowdown. The relationship between the change of labor force composition and productivity is examined in section IV. Different lag variables of labor composition are used to test the hypothesis that this change may be a factor slowing labor productivity growth. In section V, the time series model, addressing the relationship between information technology and the change of labor force composition, is presented. The model suggests that IT investment can increase the ratio of the number of information workers to the total number of workers. A more complex model for understanding the impact of IT and change of labor force composition on productivity is provided in section VI. Finally, in section VII, the conclusion is made that IT investment does have a positive contribution to economic growth, while at the same time accelerating the change of labor force composition. The change of labor force composition is posited as the major force that reduces economic growth.

II. RESEARCH INTEREST

The research on business value of information technology (IT) is of concern to MIS and economics researchers because evidence on the contribution of IT investment to the creation of business value is thus far inconclusive. Although the term business value of IT embraces many facets of the impact of IT investment (which may be far more than “productivity” itself), productivity has been widely and traditionally accepted as the bottom line of any investment (Brynjolfsson 1993). Over decades, many researchers could not find a positive relationship between IT and business value. For example, Berndt and his colleagues reported a negative correlation between high-tech capital and labor productivity and (Berndt and Morrison 1995; Berndt et al. 1992). Searching for the impact of ATMs on productivity, Franke (1987) has reported that the installation of ATMs is associated with decreased real return on equity. In addition, Loveman (1988, 1994) demonstrated no evidence of strong productivity gains from IT investments.

With more and more investment in information technology, the failure to find positive IT productivity has been labeled the IT productivity paradox. The idea was encapsulated by the famous saying of Nobel Laureate Solow, "You can see the computer age everywhere but in the productivity statistics" (Solow 1987). Since then, MIS research has been zeroing in on long-lost information technology productivity with the hope of finding some good news. For example, Barua and Lee (1997) reported positive IT productivity by employing econometric methodology. Brynjolfsson (1993) also found positive return on IT investment. In a more recent research paper, Hitt and Brynjolfsson (1994) found that computer capital is correlated with substantial increases in net output. The positive impact of information technology on business value was further affirmed (Hitt and Brynjolfsson 1996). They showed that computers were far from unproductive and that they were significantly more productive than any other type of investment made by the companies in their sample. Encouraged by those findings, many claimed that the IT paradox was gone (*Business Week* 1993), and suggested a new paradox (Bakos 1995): how can computers be so productive?

It is noteworthy that most of the papers with positive results were firm-level analyses, while research at a macroeconomic level, such as Berndt and Morrison (1995), Berndt et al. (1992), Franke (1987), and Morrison and Berndt (1990), has shown negative IT productivity. Since macroeconomic data are defined as the aggregate data in a nation or an industry, the contradiction between macro and micro-analysis would cast doubt on the external validity or generalization of firm-level analysis. In addition to the validity problem, the positive results of firm-level analysis are not able to explain the well-documented economic slowdown of the past three decades (Fischer 1988). If information technology contributes to a large portion of productivity growth and information technology investment is 25 times as large as it was 30 years ago,[1] economic growth should have been accelerated rather than slowed. Moreover, the firm-level analysis is restricted in explaining the change of the composition of the labor force in an economy as a result of the emergence and introduction of information technology (Freeman and Soete 1990). Therefore, research at this level is unable to delineate the relationship between the change of the labor force composition and any continuous slow productivity growth, or to investigate the role information technology plays in the general equilibrium of the economy. To be more specific, changes in labor force composition mean here a change in the number of workers in the information and production sectors. I conjecture that the change of labor force composition, while fostered by increasing IT investment, may offset the contribution from IT investment to labor productivity.

Because of the limitations ascribed to firm-level analyses, this research is conducted at a macroeconomic level. Macroeconomic data are used to inquire how IT affects labor force composition and how that change affects productivity. As noted above, because the productivity slowdown of a nation is coupled with increased information technology investment, the IT productivity puzzle would become more baffling if we placed our focus only on national data. Also noted above, however, is another economic trend of the past few decades: the change of labor force composition, signified by the change of the nature of employment. Just as postwar employment changed when people moved from agricultural sectors to production sectors, the past 30 years are a history of people moving from production sectors to information sectors. The suspicion here is that the change of labor force composition complicates the causal relationship between information technology investment and productivity. The past economic trend will be triangulated and the IT productivity paradox untangled by examining the change of

[1]The evidence will be provided later in this paper.

labor force composition. Three facets of the economic trend discussed above will be remarked upon:

- How employment change affects productivity.
- How information technology shapes the employment structure.
- How information technology affects productivity by way of the changing labor force composition and its direct relationship with productivity.

III. ECONOMIC SLOWDOWN AND POSSIBLE EXPLANATIONS

Following the fast economic recovery after World War II, the economy since the late 1960s has been perceived as sluggish. In the 1960s, the U.S. labor productivity growth rate was 2.68%. It dropped to 1.26% in the 1980s. Such an economic growth slowdown is not unique to the U.S. Many OECD countries, including Japan, experienced a similar trend. The labor productivity of different countries is summarized in Table 1, where labor productivity is calculated by dividing total production by the total number of employees engaged. Data are from the OECD International Sectoral Database (OECD 1998a). All averages are arithmetic.

Table 1. Labor Productivity Growth Rate of Selected Countries

	1960s	1970s	1980s	1990[a]
Australia	1.79	0.79	-1.07	1.96
Canada	3.24	0.66	0.06	0.64
Japan	12.10	3.52	1.97	1.53
U.K.	2.41	1.31	1.94	-0.57
U.S.	2.68	1.25	1.26	1.46

[a]Due to data availability, the Australia data are up to 1992, Canada to 1996, Japan to 1996, U.K. to 1990, and U.S. to 1998.

As we can see from Table 1, productivity slowdown is an international phenomenon with some countries suffering more than others. Australia, for example, exhibits the most serious sluggishness. Its labor productivity growth was 1.79% in the 1960s, which was already lower than most other industrialized countries, and productivity growth dropped further to -1.07% in the 1980s. Even a fast-growing industrialized country like Japan could not avoid the slowdown. Its labor productivity growth declined from a high of 12.1% to 1.97% in the 1980s.

Productivity can be measured in multifactor or single-factor form and productivity slowdown is not restricted only to labor productivity (Bureau of Labor Statistics 1997). Labor productivity is measured by the total output divided by the number or workers or by the total hours of employment. Total factor productivity is the output per unit of total factor inputs—for a plant, an industry or a whole economy. The total factor productivity, also called "multifactor" or "residual" productivity, shows the efficiency of the measured entity, but does not provide information relevant to the performance of individual input. Labor productivity fills this gap by tying the contribution of labor input to the output level. For the purpose of this paper, productivity is labor productivity.

A great deal has been written in the economics literature to explain the productivity slowdown. The explanations are mostly related to technological progress and employment. First, these explanations suggest that there are lags in the diffusion of productivity gains based on technological progress from the "leading edge" to the rest of the economy. This can be proven by the different rates of growth between the high-tech sector and the overall economy. The high-tech sector is defined as electrical equipment, and electronics; information technology, automated office equipment and precision instruments; and chemicals and pharmaceuticals. In the period of 1973 to 1981, the growth rate of total factor productivity of all manufacturing in the U.S. was 0.2%, while that of the high-tech sector was 1.2%. The gap was even larger in Japan. In the same period, total manufacturing sector productivity growth was 2.9%, while the high-tech sector was

8.1% (Freeman and Soete 1990). The difference tells us that in past decades, even though the total productivity growth rate showed a downtrend, it increased in industries where technology was diffused significantly. A large portion of the output of technology-intensive industries consists of intermediate goods. For example, Leontief and Duchin (1986) estimated that 64%of the products of the high-technology sector became the inputs of other industries. As the effect of technology input on other industries cannot be seen without a time delay, it is fair to say that some time interval is required for new technology to reveal its productivity.

Second, recently developed technology is capable of increasing quality but the current measures of productivity cannot record the quality improvement that has been contributed by the new technology, mostly information technology. Quality improvement can occur in services and processes as well as in products. It is a common concern of researchers that while the quality of services and processes has improved, there is no generally accepted measurement for quality improvement. This may lead to a failure to capture some important productivity changes. The mis-measurement problem can be extended to measuring "value-added" productivity. As has been remarked by Griliches (1986), "[the measure of productivity growth used routinely by economists suffers from] difficulties in computing correctly an index based on value-added 'real' output in a world of changing commodities and services and in measuring the quantity and quality of labor service."

The third explanation of productivity slowdown resides in the change of the labor force composition of the economy—namely, the employment movement among different sectors, here labeled "employment dynamics." This issue will be addressed in-depth in section III, but here we will see how employment dynamics became an important economic trend during the past 30 or 40 years. Based on the employment data by occupations published in different Bureau of Labor Statistics handbooks, we can see a trend of workers flowing from production to information sectors. Information workers were 42.6% of all workers in 1958. In 1995, this ratio climbed to 56.4%. As the economic slowdown occurred in many countries, the change of labor force composition seems to be an international phenomenon. Both of these points are shown in Table 2.

Table 2. Information Workers as Percentage of Total Workers

	1960s	1970s	1980s	1990[a]
Australia		55.6	62.6	70.5
Canada	52.3	61.4	66.0	72.9
Japan	43.7	46.8	54.1	56.8
U.K.	52.7	51.3	59.6	68.9
U.S.	47.0	50.3	53.7	57.6

[a]The data sources and the end years are the same as Table 1 except that the U.S. data end in 1996.

Coupled with the economic slowdown, the huge increase of information technology investment has drawn researcher attention.

Investment for information processing equipment in the U.S. started at a low level of 8.4 billion dollars in 1972 and climbed to 87.2 billion dollars in 1996 (in 1992 U.S. dollars). Table 3 shows the 10-year IT investment average for five countries. The numbers are adjusted to 1992 U.S. dollars.

Table 3. Average IT Investment in Millions of U.S. Dollars

	1970s	1980s	1990[a]
Australia	926	2,595	4,458
Canada	859	3,537	7,340
Japan	6,727	31,496	74,951
U.K.	1,942	7,561	17,415
U.S.	14,341	49,170	67,975

[a]The data sources and the end years are the same as Table 1.

Due to the opposite trends of labor productivity and IT investment, it would be easy to conclude from a simple regression—with IT investment as the explanatory variable and labor productivity as the dependent variable—that IT causes economic slowdown. However, such a simple regression is not satisfactory for the following two reasons. First, the conjecture here is that the way information technology affects productivity is complex and may take years to achieve its effect because of the lag of the diffusion of productivity gains of technology progress from high-tech industry to the rest of the economy (Freeman and Soete 1990), and also because IT outputs are mostly the inputs of other goods. We believe a time series analysis, therefore, is necessary to understand their relationship. Second, an intermediary variable may be missing in a simple regression. The literature has shown that employment is one of the most important intermediary variables used to explain the IT productivity paradox (Jonscher 1983;Matzner and Wagner 1990; Sylos 1990).

IV. CHANGE OF LABOR FORCE COMPOSITION AND PRODUCTIVITY

We follow Jonscher's (1983) equilibrium model to explain the impact from the change of labor force composition on labor productivity. In his model, the economy is divided into two sectors: the information sector and the production sector. The criterion used is workers' occupations, not the industries in which they are engaged. The activity of the information sector is to process and handle information such as management, administration, accounting, brokerage, advertising, banking, education, research, and other professional services. Its workers are usually referred to as white collar. The economic counterpart consists of factory, construction, transportation, mining and agricultural activities: the blue collar labor force. In this sector, processing and handling material goods, including agricultural products, are the primary tasks. The activities they are engaged in, not the final products, differentiate the two types of workers. But an equally important factor to separate the two sectors is the skill and knowledge level each sector requires. In general, the workers of the information sector possess higher skill levels and more education, labeled as white collar in the old Bureau of Labor Statistics (BLS) classification, and it is fair to say that the productivity of information workers should be higher than that of production workers. Figure 1 shows the dynamics between these two sectors.

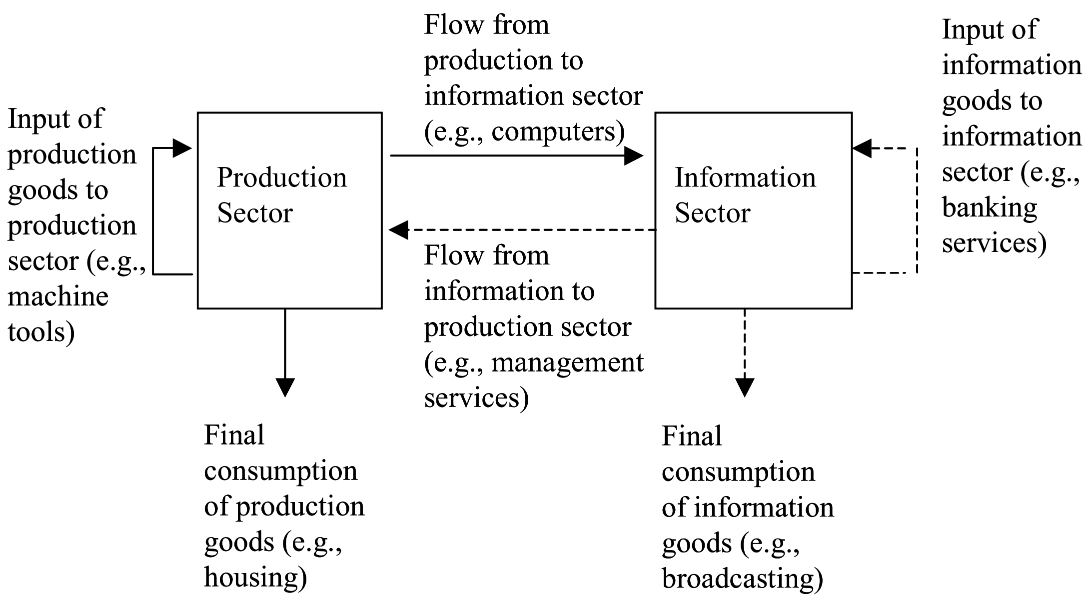

Figure 1. Dynamics of the Two Economic Sectors

One significant trend during the past decades is the expansion of the information sector. According to Jonscher, the value added (defined as the production flowing out of a sector as input to the other sector and as final consumption minus the input flowing from the other sector) in the production sector doubled while that in the information sector almost quadrupled. It is believed that this trend continues as more of the work force enters the information sector and more information products are required by producers and consumers. If the speed of expansion is faster than the speed of new employment inflow into the information sector, the economy requires that people move from the production sector to the information sector. This has been the primary drive of economic dynamics in the past few decades. The consequence of these dynamics is a productivity slowdown. That is, the more people migrate from production to the information sectors, the more productivity decreases. Intuitively, this can be explained by the fact that the productivity of blue collar workers is, in general, lower than that of white collar workers. The migration, such as the trend observed in the past 30 years, causes less-productive blue collar workers to become information workers, which gives rise to the reduction of the information sector's (average) labor productivity. Further, consider what would happen in the production sector. Workers migrating from the production sector represent a more productive portion since those moving to the information sector are more sophisticated, better educated, and more highly skilled. Because of their emigration, the labor productivity of the production sector is downgraded as well. Later on, in the Mathematical Note, this scenario is explained mathematically. On the grounds of the change in the two sectors, it is concluded that overall labor productivity would decrease. It is also not difficult to come to the conclusion that the productivity slowdown would stop when the economy comes to an equilibrium and the migration stops, other things being equal.

To support this reasoning, we not only want some mathematical proof, shown in the appendix, but some empirical analysis is also needed. Unlike IT, which has a lagged effect on productivity gains, the impact of employment change on labor productivity is instantaneous, since productivity suffers as long as less productive workers move to the information sector. To prove this point, two regressions were run to support two hypotheses:

H1: *As more workers move from the production to the information sector, the productivity growth rate is reduced.*

H2: *Productivity growth is not affected by the previous period's workforce composition change.*

The two hypotheses are tested with the following two regressions, both having productivity growth rate as the dependent variable. One regression uses the current period information workforce ratio as the explanatory variable and the other uses the current period and period (-1). The two regressions are:

$$g_t = b_0 + b_1 \left(\frac{N_I}{N_T} \right)_t \tag{1}$$

and

$$g_t = b_0^{'} + b_1^{'} \left(\frac{N_I}{N_T} \right)_t + b_2^{'} \left(\frac{N_I}{N_T} \right)_{t-1} \tag{2}$$

where N_I is number of information workers, N_T is total number of workers, and g_t is the labor productivity growth rate. The labor data are from employment by occupation from Bureau of Labor Statistics (BLS) and g_t is derived from the labor productivity data of BLS. Table 4 shows the results.

Table 4. Labor Force Composition and Labor Productivity Growth

Parameter	Estimate	t-statistic	p-value
b_0	0.3737	6.3210	.000
b_1	-0.5825	-5.3100	.000
Adjusted R-Square: 0.5418			
b'_0	.3704	6.5470	.000
b'_1	.3354	.5249	.539
b'_2	-.9196	-1.7438	.096
Adjusted R-Square: 0.5273			

The hypotheses are supported by these regressions. The first shows that, when the ratio of number of information to total workers increases 1%, productivity growth will slow down 58.25%. The very low p-value shows this regression is statistically significant. The second regression reveals that when the lag variable is introduced, the explanatory variable $\left(\frac{N_I}{N_T}\right)_t$ loses its significance and the lag variable $\left(\frac{N_I}{N_T}\right)_{t-1}$ itself alone cannot explain the change of productivity growth.

V. INFORMATION TECHNOLOGY AND CHANGE OF LABOR FORCE COMPOSITION

Even though Jonscher's (1983) model provides a good indication of the economic trend, and we can anticipate some "good news" for IT productivity in the very near future, it is not unfair to say that his model still fails to recognize the endogeneity of information technology in the economic dynamics, discussed above, and ignores the impact of information technology on employment dynamics. A question might be asked as to how IT shapes the economic structure. In the past few decades, the interaction of technological advances, employment rate, and productivity change has been under scrutiny in the economic literature, and many models have been put forward to interpret the interaction. For example, Leontief (1986) used his famous input-output table to predict the employment trend and living standard of workers from the projection of an increasing use of computers in all sectors for specific information processing and machine control tasks and their integration. He found that "by 1990 there is a progressive increase in the proportion of professionals and a steep reduction in the number and proportion of clerical workers" (Leontief 1986). In the model discussed here, the assumption is that the economy at the aggregate level keeps the optimal capital/labor combination; that is, we assume that economic expansion follows an unbiased pattern. The aggregate level is a reflection of firm behavior: a firm always attempts to maximize its profit by finding the optimal input factor vector. Therefore, once technology advances and IT investment rises, a firm will adjust its labor force to align with the capital input. This scenario can be expressed in the following equation if we assume IT equipment is operated by information workers:

$$\left(\frac{N_I}{N_T}\right)_t^* = \alpha + \beta IT_t + \varepsilon_t \tag{3}$$

In Equation (3), N_I/N_T means the ratio of the number of information workers to that of total workers. IT is used to represent the IT investment. The equation alleges that the optimal number of information workers is adjusted in association with the information technology investment. The employment ratio is used instead of the total number of information workers because, as there are more production workers, more information is needed to coordinate information use in the production sector and to keep the general equilibrium. This follows the balanced growth path assumption by Solow's growth model (Romer 1996). An asterisk indicates the optimal situation, but it would be impractical to assume that the adjustment is complete and instantaneous. So, a partial adjustment model is introduced. In the partial adjustment model, the actual information employment ratio adjustment between two periods, *t* and *t-1,* is only a proportion of the optimal adjustment:

$$\left(\frac{N_I}{N_T}\right)_t - \left(\frac{N_I}{N_T}\right)_{t-1} = (1-\mu)\left(\left(\frac{N_I}{N_T}\right)_t^* - \left(\frac{N_I}{N_T}\right)_{t-1}\right) + \upsilon_t, \quad 0 \le \mu \le 1 \tag{4}$$

Combining Equation (3) and Equation (4), we can obtain the following regression:

$$\left(\frac{N_I}{N_T}\right)_t = \alpha + \beta IT_t + \mu\left(\left(\frac{N_I}{N_T}\right)_{t-1} - \left(\alpha + \beta IT_{t-1}\right)\right) + (1-\mu)\varepsilon_t + \upsilon_t \tag{5}$$

This partial adjustment time-series analysis relies on IT investment data as well as on employment data. The data used were from 1960 to 1998. The employment data sources are the same as in section III. The IT investment data were collected from National Income and Product Account (NIPA). It is defined as "information processing and related equipment" in the super category "private purchases of producers' durable equipment by type." The data set comes from the AREMOS database. The same data sets are also available from the Stat USA website at <http://www.stat-usa.gov/> and the BLS website at <http://stats.bls.gov>. The AREMOS data set is derived from NIPA, a national database maintained by the Department of Commerce. This database has been widely used by the Bureau of Economic Analysis and other private companies such as Citicorp and the WEFA Group from Wharton School of Business. The parameter estimates are shown in Table 5.

Table 5. IT Impact on Labor Force Composition

Parameter	Estimate	t-statistic	p-value
α	.483161	66.2017	< 0.01
β	.00120054	7.83341	< 0.01
μ	.590908	2.77439	< 0.01
Adjusted R-Square: .933479			

We can see from the p-values of Table 5 that both estimates, α and β, are significant at the 95% confidence interval. The unit for IT investment is in constant billion dollars of 1980 so this regression reveals the fact that for every one billion dollar investment in information technology, the information workers will post a 0.12% increase in the total labor force.

VI. THE IMPACT OF IT AND CHANGE OF LABOR FORCE COMPOSITION ON PRODUCTIVITY

The preceding section demonstrated IT's impact on employment. This section presents a model the impact of employment and IT on productivity. Jonscher's (1983) model exhibits a good indication of productivity by the employment ratio, but he did not articulate the employment impact on productivity growth rate (for a critique on Jonscher's misconception of productivity growth, see Nightingale 1988). A growing productivity does not accommodate slowdown. When economists talk about "slowdown," they mean the reduction of growth rate even though the economy still undergoes positive growth. The assumption here is that the productivity of all individuals follows a uniform distribution with a constant interval between two adjacent workers, and further that all production workers have lower productivity than information workers. The variables are listed in Table 6.

Table 6. Variable Description

Variable	Meaning
G_t	Average labor productivity of the whole economy
$G_{i,t}$	Information sector labor productivity
$G_{p,t}$	Production sector labor productivity
G_t^k	k^{th} individual's productivity
g_t	Total labor productivity growth
$g_{i,t}$	Information sector labor productivity growth[a]
$g_{p,t}$	Production sector labor productivity growth
N_t	Total number of workers
n_t	Number of workers migrating from production to information sector
ζ	Productivity difference between two adjacent workers, a constant
G_t^u	Upper bound productivity, = $G_{i,t}^u$
G_t^l	Lower bound productivity, = $G_{p,t}^l$
$G_{p,t}^u = G_{i,t}^l$	Upper bound productivity of production sector or lower bound productivity of information sector
IT_t	Information technology investment

[a]Based on Jonscher's (1983) calculation.

The number of employees migrating from the production to the information sector (n_t) is calculated from the following assumptions. Suppose that there is no migration. The rate of increase in each sector should then be the same as the increase rate of the total number of workers. The difference is caused by the migration. This assumption can be illustrated in the following calculation:

$$n_t = N_{I,t} - N_{I,t-1} \cdot N_t / N_{t-1} \tag{6}$$

As noted above, the migration will cause a productivity reduction in both sectors. Following the model assumptions, we can see that the reduction is equal to $(n_1 - 1)\zeta$ since ζ is the productivity difference between two adjacent workers. After some mathematical derivation, we can obtain the following relationship:[2]

$$g_{t+1} = \theta \cdot \frac{n_t}{N_t}, \tag{7}$$

and $\theta = -\frac{1}{2}\frac{G_t^u - G_t^l}{G_t^u + G_t^l}$, where n_t / N_t is the migration ratio; i.e., the number of workers moving from production to information sector/total number of workers. From the Mathematical Note, Part D, we can see that θ is a time-invariant constant parameter whose value is to be estimated. If there is no information technology investment, Equation 7 can be the regression to estimate the impact of employment dynamics on the growth rate. By doing this, however, we still ignore the influence from information technology investment. To incorporate IT investment into the model, assume that the k'th individual increases his productivity due to the investment by $\eta\left(\frac{IT_t}{N_t}\right)$. Therefore,

$$G_{t+1}^k = \left(1 + \mu\left(\frac{IT_t}{N_t}\right)\right)G_t^k \cdot \tag{8}$$

[2]Please see the mathematical note for mathematical details.

Equation (8) states that an individual's productivity is determined by his previous period's productivity G_t^k and the average personal information technology investment IT_t/N_t. The η is the productivity per dollar of IT investment. It can be proved from the Mathematical Note that

$$G_{t+1} = \left(1 + \eta\left(\frac{IT_t}{N_t}\right)\right)G_t. \tag{9}$$

Equation (9) thus is IT investment's impact on productivity at an aggregate level. Combining Equation (7) and Equation (9), and assuming constant return to scale, we obtain

$$g_{t+1} = \eta\left(\frac{IT_t}{N_t}\right) + \theta\frac{n_t}{N_t}. \tag{10}$$

Equation (10) thus provides the macroeconomic explanation of productivity growth under the impact of information technology investment and employment dynamics. After running an autoregressive model by using the U.S. data from 1960 to 1998[3] and performing diagnosis checking for correct specification of order, we obtain the parameter estimates in Table 7.

Table 7. IT and Migration Impact on Labor Productivity

Parameter	Estimate	t-statistics	p-value
η	.00264745	2.49230	< 0.01
θ	-2.85387	-4.19147	> 0.01

[3]In order to explain the parameters more easily, we change the units of the following variables: *IT*: U.S. dollars for 1980; *N*: person; *n/N* and *g*: percentage. All the variables come with subscript *t*.

Both estimates are significant at the 95% confidence interval. It shows that as more workers move from production to information sectors, the productivity growth will be slower. Whenever the employment migration ratio attains a 1% increase, the labor productivity growth rate will be reduced 2.85%. The model also shows that IT investment has positive contributions to productivity growth, and whenever the dollar of IT investment for a person is made, labor productivity gains 0.0026%. This confirms our assumption that IT productivity is compounded by the change of labor force composition and can be ascertained if the change of labor force composition comes to an equilibrium.

VII. CONCLUSION

This paper has provided data to demonstrate the economic slowdown of the past 30 years and to highlight the change of labor force composition of the economy in the same period. Several explanations of the economic slowdown have been provided in the literature, such as the technology diffusion problem and an unsatisfactory measurement of information technology contributions. The noticeable change of labor force composition was found to be a significant cause of the economic slowdown. In this paper, evidence is first provided of how change of labor force composition slows labor productivity. Jonscher's (1983) model of dividing the economy into production and information sectors was adopted. The "change" is the work force migration from production to information sectors and such change caused the economic slowdown. The paper has also shown that information technology investment can cause a change of labor force composition, which, in turn, has an impact on productivity. Simply put, IT causes migration from production to information sectors, and this migration, in turn, reduces productivity growth. The causal relationship of IT and change of labor force composition has been attested to by the econometric model developed with very high levels of fit. Finally, a model was developed to show how productivity growth rate can be affected by IT investment per capita IT_t/N_t and by the ratio of migrating workers to the total number of workers n_t/N_t. This model has confirmed a negative impact of the migratory ratio on productivity. It also derives positive IT contributions to labor productivity. With IT investment and productivity growth going in opposite directions in the past 30 years, this result should be considered as good news for those who are trying to unravel the IT productivity paradox. A positive significant estimate is expected when, first, the new technology created in high-tech industry diffuses into other industries and the growth of the industries are kept balanced; second, a measurement of productivity can be developed to record quality improvement and added value; third, the change of labor force composition reaches equilibrium or even leads to the opposite direction, i.e., information workers migrating to the production sector.

In addition, this paper provided a contribution in terms of level of analysis. It investigated the IT productivity paradox at a macroeconomic level and mitigated generalization problems inherent in traditional firm-level approaches. The macro-economic-level approach also provides a viewpoint for the change of labor force composition, which has been proven to be an important factor in the IT paradox. However, because the results obtained here are solely based on U.S. data, they are less conclusive and must be confirmed by analyzing data for other major countries, e.g., Australia, Canada, Japan, and the U.K.

One important implication is how this research is related to the "New Economy" concept. As the paper identified, the migration of production labor to the information sector is a major force hampering the contribution of IT to labor productivity, and IT investment itself fosters such migration. However, it has also been shown that IT investment can increase labor productivity growth. One hypothesis can be that when the migration stops and IT investment continues, labor productivity growth will jump. Many journal articles have claimed that IT creates the New Economy and we may well enjoy the prosperity of this Golden Age. Can this paper and the trend in the composition of the labor force give us some hint?

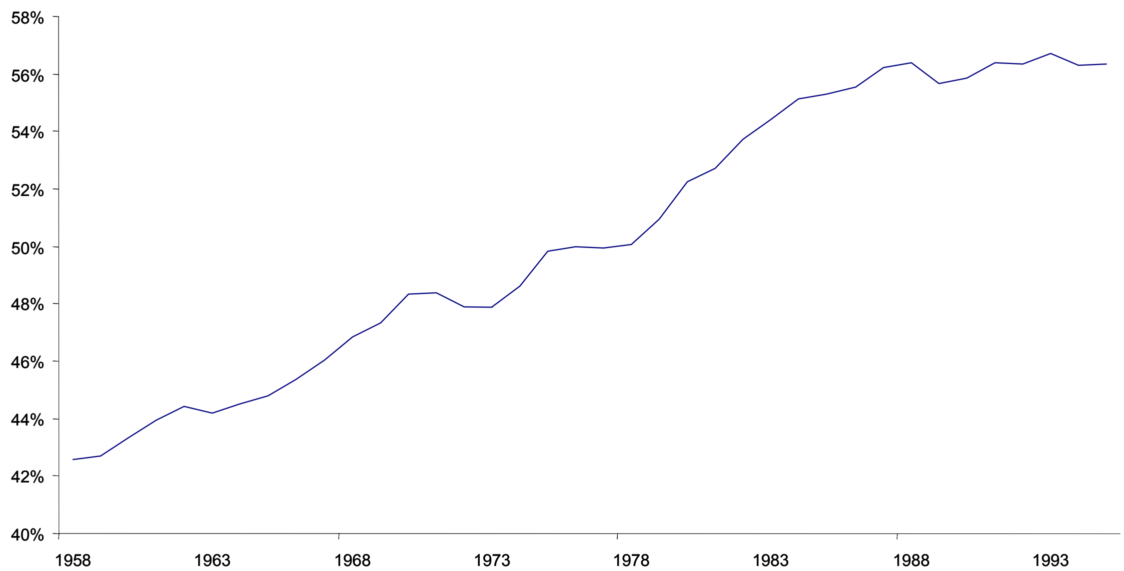

Figure 2. Ratio of Information Workers to Total Workers in the U.S.

Figure 2 is the ratio of the number of information workers to total workers in the U.S. This figure demonstrates a possible optimistic outlook: its peak appears indistinctly in the early 1990s and, if our hypothesis is correct, this would be the opportunity for productivity growth to bounce back. Several implications would be expected when productivity growth turns around. First, the IT productivity paradox would be a minor phenomenon, i.e., restricted to individual firms and not a nationwide problem because the national productivity would then display positive growth. Second, the information technology would realize its productivity potential after the economy makes the adjustment to its optimal employment composition. During the past few decades, while IT investment gained momentum, the economy entered a stage of dynamic interaction between the two sectors of workforce and, therefore, the change of labor force composition diluted the effect of information technology on productivity. After the structure of the economic system achieves equilibrium, the potential impact of IT will emerge as the employment ratio levels off. Finally, this paper opens up a possibility that economic growth would resemble other fast-growing eras, such as the postwar period, since the economy will reach its labor equilibrium and thus the potential effect of IT investment will guide the economic trend.

Although this argument is in its very early stage and we still need researchers to build theories to prove it, the concept of the New Economy has been proposed by the business world. One proposal was made by Stephen Shepard in *Business Week* (1993). He states, “By the New Economy, we mean two broad trends that have been under way for several years. The first is the globalization of business.…The second trend is the revolution in information technology.” The belief expressed here is that information technology is a transcendent technology, like railroads in the 19th century and automobiles in the 20th century, and provides a way to return to the high-growth, low-inflation conditions of the 1950s and 1960s. This research found that executive after executive, in industry after industry, reported no need to raise prices because productivity increases were sufficient to boost profits. However, a lack of macroeconomic evidence is admitted. The findings reported here have actually captured some key evidence of this New Economy. First, when the economy was on its migration from the production to the information sector, the macroeconomic productivity gains were lost by the migration. Second, when the employment structure approaches equilibrium, we start to see a productivity growth boost, and we have seen that its current level is more like the one in the 1960s. Will this trend continue and will we eventually reach a stage proposed by Shepard of a 4% productivity growth rate? We hope to see the answer when more new data are available.

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[4]Editor's Note: The following reference list contains hyperlinks to World Wide Web pages. Readers with the ability to access the Web directly or are reading the paper on the Web can gain direct access to these linked references. Readers are warned, however, that

1. these links existed as of the date of publication but are not guaranteed to be working thereafter.
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IX. ABOUT THE AUTHOR

Wesley S. Shu is an assistant professor in the Information and Decision Systems Department San Diego State University. His research is focused on information technology productivity.

Appendix
Mathematical Note

A. BASIC ASSUMPTIONS

To derive the econometric model, we first need the following assumptions without loss of generality. The variable names are listed in Table 6.

1. The productivity of all the individuals follows a uniform distribution; thus,

$$G_t^k \in \left[G_t^l, G_t^u\right], \forall k, 1 \le k \le N_t,$$

and the average labor productivity is

$$G_t = \frac{1}{2}\left(G_t^u + G_t^l\right). \qquad \text{(A.1)}$$

The same convention can be applied in either production or information sector:

$$G_{i,t} = \frac{1}{2}\left(G_t^u + G_{i,t}^l\right), \qquad \text{(A.2)}$$

and

$$G_{p,t} = \frac{1}{2}\left(G^u_{p,t} + G^l_t\right). \tag{A.3}$$

2. ζ represents the productivity difference between two adjacent workers, so by definition,

$$\varsigma = \frac{G^u_t - G^l_t}{N_t - 1} \tag{A.4}$$

3. When workers move out of the production sector, that sector loses some of its most productive workers. So, the upper bound of the production sector productivity becomes

$$G^u_{p,t+1} = G^u_{p,t} - (n_t - 1)\zeta \tag{A.5}$$

Similarly, after the move, the information sector acquires the workers who comprises the lowest productivity part, and the new lower bound of information sector productivity becomes

$$G^l_{i,t+1} = G^l_{i,t} - (n_t - 1)\zeta \tag{A.6}$$

B. HOW MIGRATION REDUCES LABOR PRODUCTIVITY

Follow the above assumptions and suppose both sectors have an equal number of workers and both the lower bound and the upper bound of the whole economy is not changed, i.e., $G^u_t = G^u_{t+1}$ and $G^l_t = G^l_{t+1}$. The average of labor productivity in period *t*, G_t is $\frac{1}{2}(G_{p,t} + G_{i,t})$. Here, $G_{p,t} = \frac{1}{2}(G^l_t + G^u_{p,t})$ and $G_{i,t} = \frac{1}{2}(G^u_{p,t} + G^u_t)$. After migration, the upper bound of the production sector's productivity, which is equal to the lower bound of the information sector's productivity, is moved from $G^u_{p,t}$ to $G^u_{p,t+1}$ and $G^u_{p,t} > G^u_{p,t+1}$. The new average labor productivity of production sector,

$$G^p_{t+1} = \frac{1}{2}\left(G^l_{t+1} + G^u_{p,t+1}\right) < \frac{1}{2}\left(G^l_t + G^u_{p,t}\right) \tag{A.7}$$

and

$$G_{i,t+1} = \frac{1}{2}\left(G^u_{p,t+1} + G^u_{t+1}\right) < \frac{1}{2}\left(G^u_{p,t} + G^u_t\right). \tag{A.8}$$

Therefore, $G_t > G_{t+1}$.

C. IT INVESTMENT'S IMPACT ON PRODUCTIVITY

For the k^{th} individual, we assume his productivity growth rate is decided by his previous period's productivity and the IT investment shared by him, so

$$g^k_{t+1} = \frac{G^k_{t+1} - G^k_t}{G^k_t} = \eta\left(\frac{IT_t}{N_t}\right)^{\gamma}\left(G^k_t\right)^{\delta}$$

The productivity, therefore, is

$$G^k_{t+1} = \left(1 + \eta\left(\frac{IT_t}{N_t}\right)^{\gamma}\left(G^k_t\right)^{\delta}\right)G^k_t. \tag{A.9}$$

If constant return to scale is assumed, we can drop $\left(G^k_t\right)^{\delta}$ and the above equation becomes

$$G^k_{t+1} = \left(1 + \eta\left(\frac{IT_t}{N_t}\right)^{\gamma}\right)G^k_t. \tag{A.10}$$

Please notice that this simplified equation still holds that an individual's productivity is decided by his previous period's productivity and the IT investment shared by him.

This equation holds true for G_t^u and G_t^l. And, since we know the average labor productivity equation,

$$G_{t+1} = \frac{1}{2}\left(G_{t+1}^u + G_{t+1}^l\right) = \left(1+\eta\left(\frac{IT_t}{N_t}\right)^\gamma\right)\left(\frac{1}{2}\left(G_t^u + G_t^l\right)\right) = \left(1+\eta\left(\frac{IT_t}{N_t}\right)^\gamma\right)G_t. \quad \text{(A.11)}$$

The productivity growth, thus, is

$$g_{t+1} = \frac{G_{t+1} - G_t}{G_t} = \mu\left(\frac{IT_t}{N_t}\right)^\gamma \quad \text{(A.12)}$$

D. CHANGE OF LABOR FORCE COMPOSITION'S IMPACT ON PRODUCTIVITY

Following the assumptions, we can obtain

$$G_{i,t+1} = \frac{1}{2}\left(G_{i,t}^u + \left(G_{i,t}^i - (n_t - 1)\varsigma\right)\right) = G_{i,t} - \frac{1}{2}(n_t - 1)\varsigma. \quad \text{(A.13)}$$

And

$$G_{p,t+1} = \frac{1}{2}.\left(\left(G_{p,t}^u - (n_t - 1)\varsigma\right) + G_{p,t}^l\right) = G_{p,t} - \frac{1}{2}(n_t - 1)\varsigma. \quad \text{(A.14)}$$

The average labor productivity is the weighted average of the labor productivity in each sector, so

$$G_{t+1} = A_{t+1}G_{i,t+1} + (1 - A_{t+1})G_{p,t+1}$$

$$= A_{t+1}\left(G_{i,t} - \frac{1}{2}(n_t - 1)\varsigma\right) + (1 - A_{t+1})\left(G_{p,t} - \frac{1}{2}(n_t - 1)\varsigma\right)$$

$$= G_t - \frac{1}{2}(n_t - 1)\varsigma. \quad \text{(A.15)}$$

The growth rate,

$$g_{t+1} = \frac{G_{t+1} - G_t}{G_t} = \frac{-\frac{1}{2}(n_t - 1)\varsigma}{G_t} = \frac{-\frac{1}{2}(n_t - 1)\frac{G_t^u - G_t^l}{N_t - 1}}{\frac{1}{2}\left(G_t^u + G_t^l\right)} \tag{A.16}$$

$$= -\frac{G_t^u - G_t^l n_t - 1}{G_t^u + G_t^l N_t - 1}$$

And when employment is very high,

$$g_{t+1} = -\frac{G_t^u - G_t^l}{G_t^u + G_t^l}\frac{n_t}{N_t}\cdot \tag{A.17}$$

From the IT impact equation, and suppose $1+\eta\left(\frac{IT_t}{N_t}\right)^{\gamma} = \Omega,$

we can rewrite

$$\frac{G_{t+1}^u - G_{t+1}^l}{G_{t+1}^u + G_{t+1}^l} = \frac{\Omega G_t^u - \Omega G_t^l}{\Omega G_t^u + \Omega G_t^l} = \frac{G_t^u - G_t^l}{G_t^u - G_t^l} \tag{A.18}$$

From that, we know $\frac{G_t^u - G_t^l}{G_t^u + G_t^l}$ is a time-invariant constant, so

$$g_{t+1} = \theta\frac{n_t}{N_t}\cdot \tag{A.19}$$

E. THE MODEL

From the above discussion about the impact of IT and migration, we obtain the regression model:

$$g_{t+1} = \eta\left(\frac{IT_t}{N_t}\right)^{\gamma} + \theta\frac{n_t}{N_t}\cdot$$

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